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Poliovirus Retention in 75-cm Soil Cores After Sewage and Rainwater Application

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Poliovirus Retention in 75-cm Soil Cores After Sewage and Rainwater Application

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The adsorption rate of a guanidine-resistant strain of poliovirus LSc 2ab was measured in Long Island soils with in situ field cores (10.1 by 75 cm). The test virus was chosen because it exhibited soil adsorption and elution characteristics of a number of non-polioviruses. After the inoculation of cores with seeded sewage effluent at a 1-cm/h infiltration rate, cores were extracted, fractionated, and analyzed for total plaque-forming units per each 5-cm fraction. The results showed that 77% of the viruses were adsorbed in the first 5 cm of soil. An additional 11% were found in the 5- to 10-cm fraction, and a total of 96% of the viruses were adsorbed by 25 cm. The remaining 4% were uniformly distributed over the next 50 cm of soil, with a minimum of 0.23% in each soil section. Few viruses (<0.22%) were observed in core filtrates. Analysis of the viral distribution pattern in seeded cores, after an application of a single rinse of either sewage effluent or rainwater, indicated that large-scale viral mobilization was absent. However, localized areas of viral movement were noted in both of the rinsed cores, with the rainwater-rinsed cores exhibiting more extensive movement. All mobilized viruses were resorbed at lower core depths.

Disposing of treated sewage effluent via basin recharge appears to be a viable and prudent method for supplementing groundwater reservoirs. The successful implementation of such recharge practices demands a thorough knowledge of the behavior and movement of sewage-borne human pathogens in the receiving soils and groundwater. The isolation of human enteric viruses from treated sewage effluents (17, 18), as well as from groundwaters beneath wastewater recharge basins (14, 17, 18, 20) indicates that a better understanding of virus-soil interactions during the recharge process is required. Knowledge gained from an evaluation of these basic interactions could improve recharge practices and minimize virus contamination of the aquifer.

A recent review by Bitton et al. (1) indicated that many of the basic interactions which occur between viruses and soil particles have been established in soil cores or columns. These interactions seem to be regulated by: (i) the virus type (5); (ii) the composition and pH of the soil (5, 7); (iii) the conductivity of the applied wastewater (3, 11); and (iv) the rate and schedule of wastewater application (6, 11). Recently, Vaughn et al. (18) reported that the groundwaters at three recharge sites on Long Island were contaminated with human enteric viruses. Landry et al. (12), attempting to determine the factors responsible for the migration of enteroviruses through Long Island soils, reported that the extent of virus adsorption and migration was dependent upon the specific strain of virus studied. Using soil cores (4.3 by 12.5 cm) collected from operating recharge basins, the authors observed that all poliovirus types tested, including both field and reference strains, adsorbed extremely well to soils. The adsorption capabilities of other enteroviruses, however, were quite varied. Echovirus type 1 and coxsackievirus B3 adsorbed extremely well to soils, whereas echovirus type 6 demonstrated a reduced adsorptive capacity. When cores were challenged with either sewage effluent or artificial rainwater rinses, a strain-dependent pattern of virus migration was noted. Some strains could be mobilized by either type of rinse (e.g., poliovirus type 1 field and mutant strains and echovirus 6 reference strain), whereas other enteroviruses were eluted only by a rainwater rinse (e.g., poliovirus type 3 reference and field strains). Reference strains of poliovirus type 1 and echovirus type 1 were not mobilized by either rinse. Because the cores used in these experiments were only 12.5 cm in length, the authors were not able to ascertain whether the mobilized enteroviruses would resorb or migrate significant distances in the soil. To assess the resorption potential of mobilized enteroviruses to recharge basin soils, the present study employed soil cores (10 by 75 cm).

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All experiments were conducted in situ at an operating recharge facility. The virus employed in all studies was a guanidine-resistant strain of poliovirus LSc, which had previously been shown to have soil adsorption and elution characteristics similar to a number of non-poliovirus types (12).

MATERIALS AND METHODS

Virus and host cells. A guanidine-resistant mutant of poliovirus type 1 strain LSc was used in all experiments (courtesy of D. Tershak, The Pennsylvania State University; 16). An initial analysis of the adsorption and migration characteristics of this virus in Long Island soils was previously presented (12). The virus was propagated on monolayers of low-passage Buffalo green monkey kidney cells (Microbiological Associates, Bethesda, Md.) grown in Eagle minimum essential medium with Earle balanced salt solution, supplemented with 10% fetal calf serum and antibiotics (penicillin, streptomycin, and gentamicin). Viruses were maintained in monodispersed stocks after the removal of aggregates by passage through serum-treated 50-nm filters (9).

Virus assay. Viral enumerations were carried out on monolayers of Buffalo green monkey kidney cells in 25-cm^2 culture flasks. Sample volumes of 0.5 ml were placed on replicate cell monolayers and incubated with continuous rocking for 1 h. After decanting excess inoculum, monolayers were overlaid with 4 ml of plaquing medium (minimum essential medium) containing 0.8% agar. After incubating 1 to 3 days, monolayers were stained with a second agar layer containing neutral red. Plaque development was observed for a period of 5 days.

Basin and soil characteristics. All experiments were carried out in situ in an experimental recharge basin located in Medford, N.Y. The facility, operated by the U.S. Geological Survey, has been described previously (17). During the construction of the basin, the surface and subsurface soils were removed to the substratum level; thus, the remaining basin soils represented a C horizon. These soils consisted primarily of coarse sand and fine gravel and contained an average of 1.12% silt and clay. The clay minerals in the soil were primarily kaolinite and illite (R. Prill, personal communication). A particle size analysis of soils in the basin's unsaturated zone is shown in Table 1. The soils had a single grain structure and contained little organic matter. The cationic exchange capacity of the soil was 0.70 meq/100 g, and the bulk density was 1.59 g/cm^3. The soil was generally considered to be strongly acidic, with a pH ranging from 5.1 to 5.5. However, when the soil surface was clogged with particulate matter after prolonged recharge, the ambient pH increased to 7.4. The soil was highly permeable, with a maximum infiltration rate of 1.5 m/h at 20°C (R. Prill, personal communication). Preliminary evidence indicated that the soil was a Plymouth A series type (19).

Core experiments. Before initiation of the actual experiments, the experimental recharge basin was continuously flooded over a 2-week period with chlorinated, tertiary-treated effluent at a rapid infiltration rate (~75 cm/h) to insure complete flushing of the upper soil levels. The infiltration rate was then reduced to <5 cm/h by clogging the basin surface with particulate-laden sewage effluent. Recharge was then halted, and the basin was allowed to drain so that core tubes (10.1 by 121 cm) made of polyvinylchloride builder's pipe could be driven into the basin surface to a depth of 100 cm. Basin recharge was then resumed until the infiltration rates of the individual cores measured less than 5 cm/h. For each experiment, five cores were placed in the basin, and those matched by similar infiltration rates were used for the experimental run (average rate in all experiments was 0.5 to 2 cm/h). All experiments were performed in triplicate.

TABLE 1. *Particle size analysis of test basin soils from unsaturated zone*[a]

Particle diam (mm)	% Composition at depths (m) below basin surface:		
	0.75	2.25	5.34
Silt and clay			
<0.0625	0.30	0.75	1.2
Sand			
0.0625–0.125	0.4	1.8	1.6
0.125–0.250	3.3	23.5	10.9
0.250–0.5	14.1	27.5	25.2
0.5–1	36.4	25.8	36.3
1–2	13.4	4.1	6.2
Gravel			
2–4	6.9	4.2	4.3
4–8	6.4	4.1	4.3
8–16	9.6	8.0	6.2
16–32	9.3	0.0	3.5
32–64	0.0	0.0	0.0

[a] Courtesy of R. Prill (unpublished data, U.S. Geological Survey, Syosset, N.Y.).

The general procedure for each experiment was similar. Experimental cores were allowed to drain and then inoculated with 2-liter (~21 cm) volumes of unchlorinated tertiary effluent seeded with a guanidine-resistant strain of poliovirus type 1 (LSc 2ab g') to a final concentration of approximately 10^3 plaque-forming units (PFU)/ml. The seeded sewage effluent was then allowed to drain through the soil surface. Control cores were then capped and excavated from the basin and returned to the laboratory for analysis. Remaining cores were given a 2-liter rinse with either tertiary-treated effluent or artificial rainwater. The composition of the rainwater, which represented the anion and cation content of rainfall in the northeastern United States, has previously been described by Landry et al. (12). After drainage of the appropriate rinse through the soil surface, cores were capped, excavated from the basin, and returned to the laboratory for analysis.

The soil from each core was collected in 5-cm fractions (approximately 500 g/fraction) and stored in plastic bags at 4°C to await extraction. Viruses were extracted from soil samples by adding 500 ml of a 3% beef extract–0.5 M tris(hydroxymethyl)aminomethane buffer solution (pH 9.5), vigorously mixing for 5 min, and sonicating (Heat Systems-Ultrasonics, Inc.; model W-220F) at 100 W for 10 min. After centrifugation (7,500 × *g* for 10 min), supernatant fluids were

collected and acidified to pH 3.5 with 1.2 N HCl. The resulting organic floc was collected by centrifugation (7,500 × *g* for 10 min), and the pellets were dissolved in 10- to 15-ml volumes of dibasic sodium phosphate (pH 9.5). After neutralization to pH 7.0, samples were assayed for virus activity as described above. The overall efficiency of the soil extraction method was 30%. Although this would likely influence the total number of viruses isolated, it was assumed that the relative proportions of virus which were isolated between fractions or cores extracted on the same day would be constant.

Virus enumerations were determined for each of 4 to 6 replicate flasks per dilution. Means and standard deviations of each sample were calculated from the normally distributed common logarithms of the data. All additional statistical analyses were performed according to Sokal and Rohlf (15).

RESULTS

Distribution of LSc g′ in soil cores. Landry et al. (12) reported that 72% of guanidine-resistant polioviruses seeded in sewage effluent were adsorbed to 12.5-cm soil cores collected from operating recharge basins. Although later experiments demonstrated that nearly all of these viruses could be adsorbed by passage through 75 cm of the same soils (J. M. Vaughn, E. F. Landry, C. A. Beckwith, and M. Z. Thomas, submitted for publication), no information was available on the likely distribution of these viruses in the soil. We therefore investigated the adsorption profile of this virus employing cores (10.1 by 75 cm) placed in an operating recharge basin. After complete infiltration at a rate of 1 cm/h, poliovirus-seeded cores were fractionated in 5-cm increments and analyzed for total PFU. The results, presented in Fig. 1, show the virus recovery per fraction expressed as a percentage of the total PFU recovered. The data indicated that 77% of the viruses were adsorbed during passage through the first 5 cm of soil. An additional 11% were adsorbed in the next 5 cm of soil. Over 96% of recovered viruses were adsorbed before the 25-cm soil depth. The remaining 4% were uniformly distributed over the next 50 cm of soil, with each section containing a minimum of 0.23% of the total viruses recovered. Because these were in situ experiments, no estimates of the number of viruses passing through the entire length of the core could be obtained.

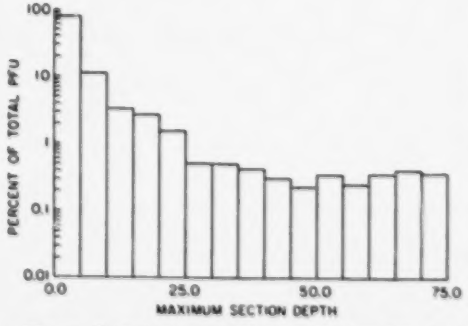

FIG. 1. *Distribution profile of poliovirus LSc 2ab g′ in soil cores (10.1 by 75 cm).*

Apparent virus adsorption rates after sewage effluent or rainwater rinses. Recent studies indicated that the test virus could desorb and move at least short distances (<12.5 cm) in soil cores after the application of sewage effluent or rainwater rinses (12). To determine whether the rate of virus adsorption over the length of the core, as observed in Fig. 1, could be altered by such applications, a series of seeded soil cores was challenged with 2 liters of either rinse. After complete infiltration of the rinse, the cores were removed, fractionated, and analyzed as before for the total PFU recovered per fraction. To statistically compare the rates of adsorption after the various treatments by linear regression analysis, the data sets had to be normalized by a $\log_{10}$ transformation of both the x (maximum section depth) and y (PFU recovered per section) coordinates. The results, shown in Fig. 2, are the best-fit regression lines which describe viral adsorption in soil cores after: no additional treatment (control); a sewage effluent rinse; and a rainwater rinse. All regression lines for the cores were significant ($P < 0.001$) for each data set, with coefficients of determination (r^2) ranging from 0.74 to 0.76. To determine whether there were any significant differences in the rates of viral adsorption as defined by the slopes of the regression lines, a test for the equality of slopes was performed (15). The results indicated that the slopes for each treatment mode were not significantly different ($P > 0.05$), suggesting that the rate of virus adsorption remained essentially unchanged, regardless of treatment. The same pattern was observed in three replicate experiments (data not shown).

Extent of virus migration through the entire 75-cm core. Since the data presented in Fig. 1 illustrated the movement of a small but consistent population of viruses to lower core areas, it was important to determine quantitatively the number of viruses which could move through the entire core during the initial application and in response to the various rinses. Several cores, collected from recharge basins, were returned to the laboratory and inoculated with 2 liters of an LSc g′-containing sewage effluent (~2×10^3 PFU/ml). After complete infiltration of the sewage effluent at a rate of 1 cm/h, core filtrates were collected and analyzed for unadsorbed viruses. The results showed that

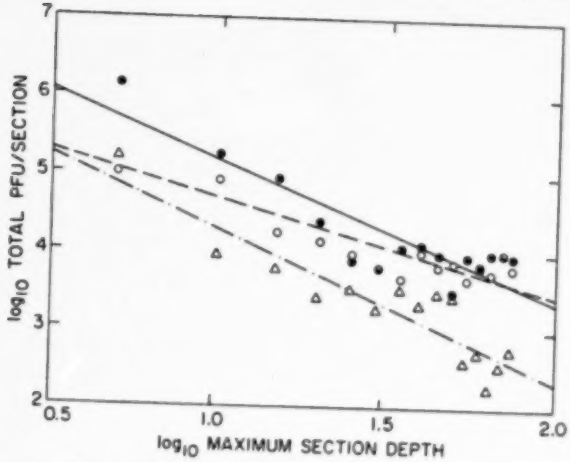

FIG. 2. *Best-fit regression lines for virus distribution in nontreated cores, sewage effluent-rinsed cores, and rainwater-rinsed cores. Data points represent means of at least three replicates. Symbols: —●, No treatment, $y = 6.953 - x \cdot 1.791$, $r^2 = 0.752$, $n = 58$; - - -△, sewage-rinsed, $y = 6.236 - x \cdot 1.930$, $r^2 = 0.767$, $n = 45$; —○, rainwater-rinsed, $y = 5.891 - x \cdot 1.223$, $r^2 = 0.741$, $n = 59$.*

less than 0.22% of the input viruses were able to move through the entire length of the core. Subsequent treatment of the cores with either a sewage effluent or a rainwater rinse resulted in the release of an additional 0.16%, demonstrating that a single application of either type of rinse was not sufficient to cause substantial virus elution and movement through the cores.

Localized virus migration and resorption during sewage and rainwater application. Although the data presented above demonstrated that the overall rate of virus adsorption in soil cores was not significantly changed after the application of sewage or rainwater, some limited virus migration through the entire core was observed. This indicated that localized areas of virus migration and resorption might be present within the cores. To examine more closely the variations which might occur within confined regions of a 75-cm core after various treatment schemes, three in situ field cores were seeded with poliovirus and processed as previously described. The resulting data were examined by a two-way analysis of variance, followed by a comparison of the means using a least-significant-difference technique (15). This method allowed for the grouping of statistically similar fractions from all core types. The analysis of variance, shown in Table 2, indicated that significant differences ($P < 0.001$) existed between similar fractions of the various cores. Furthermore, the interaction term was also significant ($P < 0.001$), indicating that although differences were present between cores at some levels, they may not have been present at all levels. Table 3 presents the results of the least-significant-difference analysis, with the core sections arranged in order of decreasing magnitude, based upon the percentage of virus adsorbed per section. The data indicated that the percentage of virus adsorbed in the top 5 cm of soil of each experimental core (e.g., no treatment, sewage or rainwater rinsed) did not differ significantly ($P > 0.05$). At the 5- to 10-cm depth, a greater number of viruses (18.25%) were observed in rainwater-rinsed cores than in either sewage-rinsed (4.36%) or control cores (9.29%). It is of interest to note that in the 10- to 15-cm section, there were no significant differences ($P > 0.05$)

TABLE 2. *Two-way analysis of variance of the effect of core treatment and sample depth on virus distribution*

Source of variation	DF[a]	SS[b]	MS[c]	F_s[d]
Among core types	14	43.3044	3.0931	109.30[e]
Among core depths	2	5.2207	2.6103	92.24[e]
Interaction of core types and depth	28	5.8910	0.2103	7.43[e]
Within subgroups	90	2.5473	0.0283	

[a] DF, Degrees of freedom.
[b] SS, Sum of squares.
[c] MS, Mean squares.
[d] F_s, Calculated value.
[e] $P < 0.001$.

between the proportions of virus in all three cores. Although the subgroupings became more complicated at greater core depths, several general trends could be identified. The lower one-third of Table 3 includes only the lower core sections of sewage-rinsed (S-55 to S-75) and control cores (C-45 to C-75), whereas the intermediate portion of the table, which represents sections with higher percentages of virus, is dominated by the deeper sections of the rainwater-rinsed cores (R-55 to R-75). This indicated that the deeper sections of the rainwater-rinsed cores contained significantly greater virus proportions than comparable sections in the sewage-rinsed or control cores. Apparently, viruses from the upper core sections were mobilized and then resorbed at lower core depths. These viruses appeared to have originated below the 20-cm level, since all three cores had statistically similar amounts of virus in the 0- to 5- and 10- to 15-cm fractions, and the rainwater-rinsed cores actually had more viruses in 5- to 10- and 15- to 20-cm sections than the other two cores.

TABLE 3. *Groups of statistically similar core sections for control, rainwater, and sewage cores*

Sample and depth (cm)[a]	Groupings[b]	Mean %	Mean log %
S-5		81.02	−0.0914
C-5		63.08	−0.2001
R-5		51.11	−0.2915
R-10		18.25	−0.7387
C-10		9.29	−1.0319
C-15		4.86	−1.3132
S-10		4.36	−1.3610
R-15		4.34	−1.3622
R-20		3.10	−1.5088
S-15		2.99	−1.5244
R-40		2.78	−1.5559
R-70		2.49	−1.6033
R-25		2.20	−1.6570
R-50		1.78	−1.7486
S-35		1.69	−1.7781
S-25		1.66	−1.7810
R-45		1.61	−1.7942
R-75		1.53	−1.8139
R-30		1.46	−1.8356
S-45		1.45	−1.8374
R-60		1.35	−1.8682
S-50		1.34	−1.8732
S-20		1.26	−1.8996
C-20		1.25	−1.9018
R-65		1.19	−1.9258
S-40		1.04	−1.9816
R-35		1.02	−1.9901
R-55		0.98	−2.0088
S-30		0.88	−2.0556
C-40		0.66	−2.1800
C-35		0.57	−2.1944
C-70		0.51	−2.2940
C-65		0.51	−2.2940
C-45		0.50	−2.3052
C-75		0.46	−2.3390
C-55		0.46	−2.3390
C-50		0.43	−2.3702
C-25		0.41	−2.3878
C-60		0.38	−2.4208
C-30		0.34	−2.4743
S-75		0.28	−2.5494
S-60		0.25	−2.5951
S-55		0.19	−2.7196
S-70		0.17	−2.7693
S-65		0.09	−3.0555

[a] S, C, and R refer to sewage, control, and rainwater cores. The number after the dash is the maximum soil depth in centimeters.

[b] Designated section groups are not significantly different based upon the least-significant-difference (LSD) technique. LSD, 0.05 = 0.2757.

Sewage-rinsed cores also appeared to exhibit some redistribution of the virus population. Greater percentages of viruses were observed at 25- to 50-cm depths (S-25 to S-50) than at the same depths of control cores (C-25 to C-50). However, virus penetration in sewage-rinsed cores was not as extensive as that in rainwater-rinsed cores, since sections representing 55- to 75-cm depths contained fewer viruses than comparable sections in rainwater-rinsed cores.

DISCUSSION

Within the past few years, a number of investigators have documented the presence of human enteroviruses in sewage-recharged aquifers (13, 14, 20), including those designated as "sole source aquifers" (18). Although the public health significance of enteroviruses in groundwater remains debatable, it has been shown that 57% of all outbreaks of water-borne diseases are of suspected viral etiology (2). Such findings underscore the need to develop a better understanding of factors governing the adsorption and migration of viruses in soils during groundwater recharge operations. Regardless of the identity of the virus, the principles developed to control the migration of a wide range of enteroviruses may be useful in controlling groundwater contamination by other pathogenic, sewage-borne viruses, such as rotavirus, Norwalk-like agents, and hepatitis virus.

In a recent study using extensive field analyses, the vertical migration of a mutant strain of poliovirus was shown to be controlled by reducing the sewage infiltration rate to 1 cm/h (Vaughn et al., submitted for publication). Few viruses were detected 75 cm below the surface of the recharge basin. The results presented in this study confirm those findings by in situ core experiments which were designed to closely duplicate natural field conditions. The data illus-

trated the viral adsorption patterns of poliovirus LSc g' in the top 75 cm of recharge basin soil after the application of seeded sewage effluent. As seen in previous studies (11), the rate of virus removal at the surface was greater than that observed in the subsurface regions, with significant adsorption occurring in the top 5 cm of soil (77%). A 1-log reduction was noted by 10 cm, whereas a 2-log reduction required over 25 cm of travel in the soil. Lance et al. (11) suggested that microbial activities near the soil surface, as well as alterations of surface characteristics of soil resulting from prolonged recharge, might create better virus-adsorbing conditions. In our experiments, the soil surface mat which was generated to reduce the infiltration rate may have contained high concentrations of organic matter which contributed additional virus-adsorbing sites.

It is interesting to note the extent to which viruses migrated in the cores. Although the percentage of virus detected below the 25-cm depth was small, some viruses were always able to penetrate the entire length of the core, with 0.22% being detected in core effluent. A similar distribution pattern was recently reported by Lance and Gerba (10), using packed laboratory columns (10 by 250 cm). They reported that the distribution of poliovirus LSc was essentially unchanged over a wide range of concentrations of applied viruses. The authors suggested that charge variations within the virus population were responsible for the consistent distribution pattern. Presumably, particles with a strong electronegative charge would adsorb at the soil surface, whereas a subpopulation of viruses, characterized by a reduced negative charge, would migrate to greater soil depths. This latter population may present movement control problems since they may be more easily mobilized with repeated applications of sewage or rainwater rinses (3, 12). In addition, these viruses appeared to survive for longer periods of time than those adsorbed to surface soils (11).

Landry et al. (12) previously reported that applications of sewage and, to a greater extent, rainwater rinses led to the elution of poliovirus LSc g' from soil cores (4.3 by 12.5 cm). Unfortunately, these cores were too small to permit observations of viral resorption at greater core depths. The data presented in this study suggested that limited migration and subsequent resorption do occur, with few viruses being eluted from cores after either treatment. Since a single application of sewage or artificial rainwater did not significantly alter the overall pattern of virus adsorption in the cores, we concluded that no large-scale viral migration occurred. However, when cores were more closely analyzed, the resulting data suggested that limited, localized migration did occur after a rinse of either type. In both cases, desorbed viruses resorbed at greater soil depths with greater overall movement observed in the rainwater-rinsed cores than in the sewage-rinsed cores. These mobilized and resorbed viruses did not appear to originate from the upper core fractions (0 to 20 cm), since the concentrations of viruses in these fractions were equal to, or greater than, those observed in control and sewage-treated cores. Viruses moving in the rainwater-rinsed cores may have originated in the 25- to 35-cm core sections, since the percentages of virus in these fractions were significantly less than those in the 35- to 40- and 65- to 70-cm fractions. Duboise et al. (3) proposed that viruses adsorbed farther from the surface of a soil column could be more easily mobilized than surface-adsorbed viruses due to a decreasing ionic gradient created within the column. They suggested that ions from percolating fluids (e.g., sewage effluent) would be adsorbed at the soil surface until a point of saturation was reached. Fewer ions would therefore be available to adsorb at greater soil depths, creating a suboptimal condition for virus adsorption. Thus, the deeper-adsorbing viruses not only have had a weaker overall charge, but also a less optimal adsorbing environment. Such viruses might easily be influenced by changes in pH and ionic strength.

It is not known whether repeated applications of sewage or rainwater rinses would have caused greater viral movement. Funderberg et al. (4) and Duboise et al. (3) observed that sequential applications of sewage effluent and distilled water rinses caused low-level virus mobilization. Repeated applications of rainwater were not attempted in our experiments because of the unlikely occurrence of such large amounts of rainfall. The 2 liters of rainwater used in our experiments, representing 21 cm of rainfall, would provide a "worst-possible" model for Long Island. On the contrary, repeated applications of sewage effluent are experienced during normal recharge operations and may lead to the mobilization of certain enteroviruses. This possibility is presently under investigation in our laboratory. Lance et al. (11) suggested that alternate periods of loading and drying would prevent virus mobilization during continuous recharge operations. Drying appears to drain free water from the soil and allow the virus particles to move closer to the soil, thus promoting adsorption. The addition of divalent ions also enhanced the adsorption of the virus to the soil.

Variations in the infiltration rate of the seeded wastewater were not investigated in this study. Since all experiments were conducted at a rate

of 1 cm/h, they would clearly represent an optimal virus-adsorbing model for Long Island recharge soils (Vaughn et al., submitted for publication). Greater migration and mobilization would be expected to occur if higher infiltration rates were employed (Vaughn et al., submitted for publication). Such rates are commonly experienced in Long Island recharge basin operations and need to be investigated further (17).

Since viral adsorption to soils has been shown to be both strain and soil dependent (5, 8, 12), the data presented here represent only a single virus model. However, this model may be appropriate for a number of enterovirus types, such as field strains of poliovirus type 1 and type 3, and echovirus type 6, which have been shown to exhibit similar adsorption-mobilization profiles in smaller cores (12). Data are needed for other virus models, particularly those non-poliovirus types (e.g., echoviruses) which have been shown to adsorb poorly to soils in both laboratory and field experiments (18).

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